THE INFLUENCES OF LOCAL COMMUNITY KNOWLEDGE AND MANAGEMENT STYLES ON MANGROVE FOREST HEALTH: A CASE STUDY IN NORTHERN SENEGAL

by
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Executive Summary

For my capstone project, I wanted to focus my research on a socio-ecological project which would meld the science and policy knowledge that I gained while matriculating through the Environmental Sciences and Policy program at Johns Hopkins University. I had an opportunity to spend 10-weeks in Senegal, West Africa to conduct research on mangrove forests and interact with local residents to conduct research on how policy decisions influence ecosystem health. Mangrove forests in West-Central Africa provide essential resources to enhance the livelihoods of communities living in close proximity to the forests; however, mangroves are under threat from climate change effects and human impacts. Mangrove forest research in Senegal has historically been concentrated in the south, specifically the Saloum Delta and Casamance regions, with limited research conducted in the northern portion of the country. A close look at mangrove ecosystems in northern Senegal is needed to preserve the forests for local populations and to help mitigate global climate change effects. The objective of this study was to determine if mangrove forest health in northern Senegal is positively influenced by local community knowledge and management practices. Mangrove management styles and policies of three communities in northern Senegal were explored to determine the level of oversight within each mangrove. The knowledge of the local population in each village was assessed via questionnaire to determine how the community viewed the ecosystem services available from their respective mangroves. Additionally, an ecological assessment was completed within each study area to assess the tree health, biodiversity, and soil characteristics of the mangrove forests. The results indicate that the mangrove forest managed by the Senegalese government had the least recent dieback of mangrove trees compared to trees in mangrove forests with no management or managed only by the local community. The results also indicate that management policies like bans on resource extraction, subsidies for local communities, and informal rules-of-use influence the local community's perception of ecosystem services provided by the mangrove. This study concludes that mangrove management which incorporates local community engagement and traditional ecosystem knowledge positively influences the community's perception of available ecosystem services which then positively influences the overall health of the mangrove forests. Conducting this research has shown me that socio-

ecological research is important and necessary to get communities and policy decision-makers to work together to conserve our natural environments.

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1.0 Introduction

Mangrove forests are unique wetland ecosystems that provide a wealth of services for local populations and ecosystems around the globe. Mangrove forests are distributed along the coastal areas of tropical and subtropical regions between 30ºN to 35ºS latitude (Giri et al., 2011). These ecosystems are breeding ground for various marine and bird species, provide flood protection to coastal land, improve water quality, and sequester and store large quantities of carbon (Kauffman and Bhomia, 2017; Donato et al., 2011). Mangrove forests also provide food, timber, medicine, and other resources to support the livelihoods of local populations (Duke et al., 2007).

Africa holds 19% of the world's mangroves with 12% located in the West-Central region of the continent (Kauffman and Rhomia, 2017; Feka and Ajonina, 2011). Mangrove forests in this region have seen a significant decline in acreage within the past 20 years with an additional 25% expected to be lost by 2025 (Feka and Ajonina, 2011). Some studies suggest that natural causes such as droughts in the 1970s and 1980s along with subsequent salinization and acidification of waters surrounding the forests are to blame for the reduction in acreage in the region (Diop, 2002). Other researchers argue that the decline is a result of the "tragedy of the commons" and human deforestation activities (Feka and Ajonina, 2011; UNEP, 2007). While it may be difficult to pinpoint one overarching reason for the recent decline in mangroves in West-Central Africa, many researchers agree that it is important to conserve these forests for local population use and for the health of the global ecosystem (Diop, 2002; Feka and Ajonina, 2011; and Kauffman and Rhomia, 2017).

With a documented correlation between mangrove ecological health and its ability to sustain services (Worm et al. 2006), the loss of mangroves in West-Central Africa over the past 20 years has caused both ecological and human impacts in the form of declining fish stocks, property loss, and an increase in poverty levels (Feka and Ajonina, 2011). In Senegal, mangrove forest research has mainly been concentrated in the south, specifically the Saloum Delta and Casamance regions which fall under national and international protection policies (UNESCO, 2011). Extensive research of this specific area, and subsequent reforestation financing, has led to a 6% increase in mangrove reforestation of the Lower Casamance region between 1986-2006 (Carney et al., 2013). Little research has been conducted on mangrove forests in the northern portion of the

country where land is increasingly being grabbed for urbanization near growing cities like Somone and Saint-Louis. A close look at mangrove ecosystems is needed in these northern areas to preserve the forests for the livelihoods of local populations and to help mitigate global climate change effects.

National and regional politics and management practices play a significant role in the overexploitation of mangrove ecosystems. Mangroves have long been communal territories, used, managed, and owned by local populations (Cormier-Salem and Panfili, 2016). As of 2011, no country in West-Central Africa had a forest policy specific to mangrove ecosystems. All national and regional policy relating to mangrove management were incorporated with existing terrestrial forest or marine resource policies (Feka and Ajonina, 2011). While Barbier and Cox (2003) believe mangrove management is marginalized on the national and regional levels due to poor valuing of the mangrove ecosystem services, others see that laws and rules of the mangrove are negotiated between local communities and governmental institutions (Cormier-Salem and Panfili, 2016). Mangrove management practices in Senegal vary by location; some mangroves in the Saloum Delta are public goods in the form of national parks, some are biosphere reserves and United Nations Educational, Scientific, and Cultural Organization (UNESCO) sites, while others are public goods managed by agreements made within local communities (Cormier-Salem and Panfili, 2016).

Burkes et al. (2000) argues there are two types of ecological knowledge that impacts socio-ecological management practices: 1. Scientific ecology, and 2. Traditional Ecological Knowledge. Traditional Ecological Knowledge is a combination of knowledge, practice, and belief system which determines how humans interact with an ecosystem that has been passed down through generations (Burkes et al., 2000). In this case, Traditional Ecological Knowledge of mangrove resource conservation and extraction would include the local observational knowledge of the mangrove and the communities established rules-of-use. Traditional Ecological Knowledge depends on social mechanisms in a way that scientific knowledge does not (Burkes et al., 2000); therefore, it is important to understand the social mechanisms of local communities to understand their mangrove conservation methods.

The objective of this study is to determine if mangrove forest health in northern Senegal is positively influenced by local community knowledge and management practices by conducting qualitative and quantitative assessments of the mangrove ecosystem and local household's

perception of the ecosystem services available from the mangrove. Ecosystem services are direct and indirect benefits that humans receive from natural environments and functional ecosystems (Costanza et al., 2017 and Millennium Ecosystem Assessment, 2005). Understanding the relationship between forest health, local population knowledge, and mangrove management strategies will allow for the development of sustainable policy that could improve the health of mangrove ecosystems while also continuing to support local communities.

2.0 Methods

This study was carried out between June – August 2018 in three study areas across northern Senegal. The mangrove management style for each community was explored to determine the level of oversight within each mangrove. The knowledge of the local population in each village was assessed to determine how the community viewed the ecosystem services their respective mangrove provided. Additionally, an ecological assessment was completed within each mangrove to assess the health of each forest.

2.1 Study Areas

Study areas were selected based on discussions and contact lists for mangrove areas provided by the Ministry of the Environment. This study focused on three communities, Bango, Dieul Mbam, and Somone which were located near three separate mangrove forests in Northern Senegal (Figure 2-1). Dieul Mbam and Bango lie along the Senegal River and are located in the Saint-Louis region of the country close to the former capital city of Saint-Louis (Figure 2-2). Bango is located 5 kilometers north of Saint-Louis which has experienced significant flooding events in the 1990s and early 2000s (Vedeld et al., 2016). The mangrove in Bango is used as a common good among the community members and does not have any management oversight. Dieul Mbam is located 10.5-kilometers south of Saint-Louis and roughly 8.3-kilometers northeast of Langue de Barbarie, a marine protected area which acts as a bird sanctuary (Figure 2-2). The mangrove of Dieul Mbam is managed by the local community who have agreed upon and established rules-of-use for the mangrove. The third village, the Commune de Somone (referred to here as “Somone”) is a popular tourist destination in the Theis region of the country. Somone is located roughly 42.5-kilometers south of Senegal’s current capital city of Dakar and along the coast of the Atlantic Ocean (Figure 2-3). The mangrove of Somone is within a community nature reserve which is overseen by the Ministry of the Environment.

Figure 2-1: Study Areas

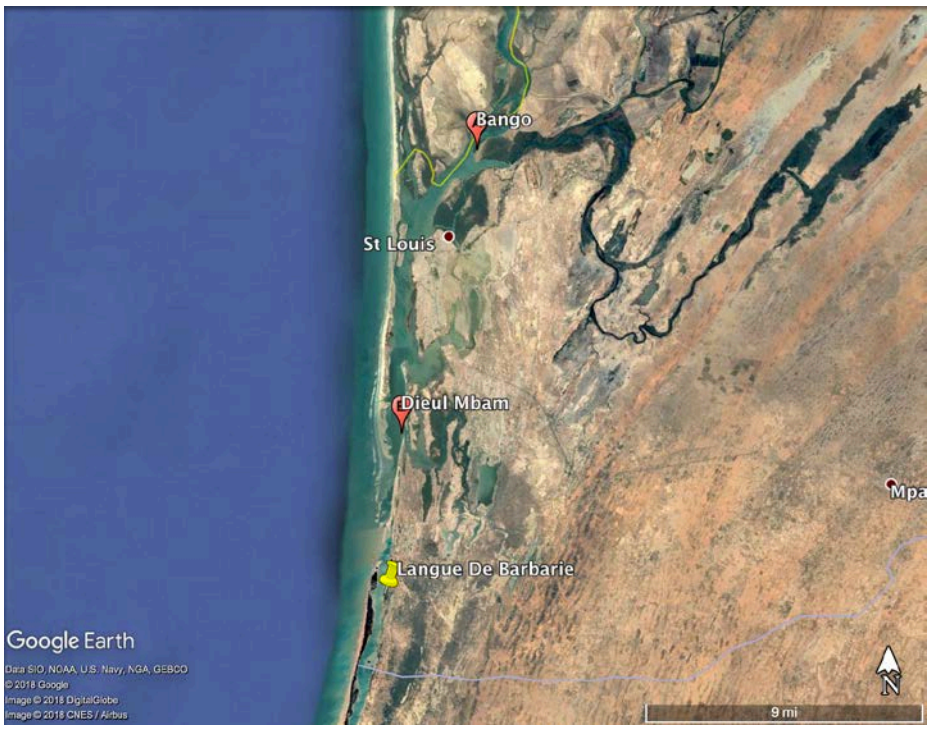


Figure 2-2: Bango and Dieul Mbam Locations

Figure 2-3: Somone Location

2.2 Mangrove Management Practices

Informal discussions with mangrove managers were conducted at each study area to understand the formal and informal rules for mangrove use, policy mechanisms used by mangrove managers, and any additional information regarding the mangroves that the manager felt was important to the overall objective of this study. Conversations in Somone were conducted in English between the researcher and the mangrove manager, while conversations in Bango and Dieul Mbam were conducted in Wolof or Pulaar with the help of a local translator.

2.3 Local Community Knowledge

A local population survey was developed and conducted in each village to determine the local community's knowledge of available mangrove ecosystem services. Initial survey participants were identified under the guidance of the mangrove manager or the village person of contact. Individuals were also selected randomly throughout the village and asked if they would participate in the survey. A snowball technique (i.e. asking participants to recommend additional people who could participate in the study) was then used to identify more survey participants in each study area (Bernard, 2017). The survey participants were asked to answer "yes" or "no" to

whether the ecosystem services listed in Table 2-1 were available from their respective mangrove forest. The ecosystem services selected for this study are a comprehensive list of services available from mangrove forests noted in the Millennium Ecosystem Assessment (2005). Discussions lasted between 30 minutes to one hour. A separate survey form was used for each participant.

Table 2-1: Mangrove Ecosystem Services

Provisioning Services	Regulating Services	Supporting Services	Sociocultural Services
Products obtained from ecosystem	***Benefits obtained from regulation of ecosystem processes***	***Services necessary for the production of all other ecosystem services***	***Nonmaterial benefits obtained from ecosystems***
• Water • Fish • Bushmeat/birds • Charcoal • Fiber • Building Material • Herbs • Insects • Medicine • Viable Agriculture	• Flood protection • Purification of Air and Water • Waste Absorption • Disease Control • Climate Regulation • Water Cycling	• Soil Formation • Nutrient Cycling • Photosynthesis • Carbon Capturing • Crop Pollination	• Ecotourism • Spiritual Attachment • Indigenous/Tribal Knowledge • Recreation

2.4 Ecological Assessments

An ecological assessment was conducted at low tide in each mangrove forest to collect parameters needed to determine the health of the mangrove forests. Mangrove tree species and health information, biodiversity monitoring parameters, and soil characteristics were collected at all three sites. The following sections detail the methodology for collecting the ecological data.

2.4.1 Mangrove Tree Health

Ten or more 2-meter by 2-meter plots were randomly selected at each site: Bango (10), Dieul Mbam (12), and Somone (10). All individual trees within each plot with heights greater than 4 meters were identified, counted, and assigned an individual identification number. If a tree

within a single plot area contained multiple trunks, each trunk was assigned a separate identification number (English et al., 1997). The number of saplings in each plot with heights between 1 and 4 meters were also counted and recorded. Field personnel identified and recorded the species and health indicators based on visual observation of leaves, flowers, and fruits of the plants. The number of dead and living trees within each plot were recorded. Mangrove tree health within each plot area were categorized based on the visual tree health indicators in Table 2-2 which were modified from Duke et al. (2010).

Table 2-2: Mangrove Tree Health Categories and Descriptors

Mangrove Tree Health Category	Descriptor
1. Healthy	Living trees; high density; No more than 20% of the canopy leaves are yellowing or indicate insect damage.
2. Unhealthy	Living trees; low density; unnatural open canopy; 50% or more of the canopy leaves are yellowing or indicate insect damage.
3. Recent Dieback	Dead trees and/or excessive receding canopies; white dead trees; leaves brown or absent with no new growth; fine limbs.
4. Old Dieback	Dead trees and/or excessive receding canopies; stumps of dead trees; no leaves or twigs; visual signs of decaying

2.4.2 Biodiversity Monitoring

To assess the fauna biodiversity of the mangroves studied, observation of the bird and crab species were conducted at each site. Bird species biodiversity was assessed by visually counting the number of birds present in the survey area. The bird count was performed twice at each mangrove by one person for 30-minutes (Holguin et al., 2006). The total number of birds was counted by surveying the fringe of each site. The crab species biodiversity was assessed by counting the number of boreholes per ten randomly selected 1-square meter at each site (Jordãno and Oliveira, 2003).

2.4.3 Soil Characteristics

Soil characteristics play a crucial role in mangrove forest health and productivity (English et al. 1997). Soil moisture and pH of the top seven centimeters of soil was measured using a

Kelway Soil Acidity and Moisture Tester field instrument. Measurements were taken either in-situ or ex-situ depending on how much water was present in the plot area and whether the field instrument would be submerged if collected in-situ. In Dieul Mbam, soil characteristics were collected in-situ at all 12 plots areas. In Somone, soil characteristics were collected in-situ at 2 plot areas and ex-situ at 8 plot areas due to 10-15 centimeters (cm) of water present within the plot areas. In Bango, soil characteristics were collected in-situ at 3 plot areas and ex-situ at 7 plot areas due to roughly 20 cm of water within the plot area. Soils at all locations were also visually classified using the Unified Soil Classification System (ASTM D 2487-83).

2.5 Data Analysis

Qualitative data (management discussions) were analyzed by categorizing the information from the discussions. Descriptive statistics were used to analyze the quantitative data (survey data and ecological data). Ecosystem service data was categorized by service and the number of "yes" responses were used to calculate percentages for each service.

3.0 Results

The following sections include results of a small set of the management discussions, survey results, and ecological assessment results but represent the summary data that was analyzed to achieve the research objective addressed in this paper.

3.1 Mangrove Management Discussion Results

Informal discussions were conducted with each identified mangrove manager and/or contact person in Bango, Dieul Mbam, and Somone to determine the rules-of-use and policy mechanisms used in each mangrove. The following sections detail the discussions within each study area.

3.1.1 <u>Bango</u>

Mr. Modou Mbaye was identified as Bango's mangrove contact person by representatives of the Ministry of the Environment. From Mr. Mbaye's perspective, there is no formal community mangrove management in Bango primarily due to the community's lack of participation. Mr. Mbaye noted that he is trying to get the community involved in mangrove conservation but is encountering resistance and does not have the trust of the people. Mr. Mbaye notes that farmers allow their cattle to freely roam the mangroves and forage on the trees. This

was confirmed during site visits due to the presence of cow droppings within the mangrove, hoof prints in the mud near the mangrove trees, and visual confirmation of cows freely roaming the village. Mr. Mbaye notes that the flood prevention measures installed by the City of Saint-Louis could be hindering water access to the mangrove which, in his opinion, is contributing to the deterioration of the mangrove forest in Bango. In 2003, as a result of these flooding events, the city opened a channel to allow the Senegal River to flow into the Atlantic Ocean and minimize potential flooding (Vedeld et al., 2016).

3.1.2 Dieul Mbam

Mr. Amet Dieye was identified as the local community mangrove manager in Dieul Mbam by representatives of the Ministry of the Environment. Mr. Dieye is recognized by Dieul Mbam's chief and community members as the mangrove protector and seems to have the respect of the community as it relates to mangrove conservation. Mr. Dieye noted that women of the village have formed two local groups who oversee the day-to-day operations the mangroves. Mr. Dieye and many survey participants noted that many current Dieul Mbam community members are displaced residents from a neighboring village, Baba Dieye, which once was in closer proximity to a different mangrove. Due to rising sea levels in the area, first documented in 2003, the historical mangrove has died and Baba Dieye is now under water. A few women in the local mangrove protection groups who were interviewed during this study noted that some members of the Baba Dieye community have brought the traditional mangrove knowledge and practices from Baba Dieye to Dieul Mbam.

According to Mr. Dieye and the women in the groups, one of the rules-of-use of the mangrove prohibits cutting of trees. The rules of the mangrove established by these groups and Mr. Dieye only allow people to extract wood from the mangrove if the wood is already on the ground. Also, according to Mr. Dieye and the group members, the women of the community have taught other community members sustainable oyster extraction methods which preserves the roots of the trees. Additionally, the village is located upstream of a marine protected area; therefore, according to Mr. Dieye, killing birds is prohibited within the mangrove. There does not appear to be any formal enforcement or consequence if someone breaks the tree cutting or bird harvesting rules of the mangrove.

3.1.3 Somone

The mangrove of Somone is within a community nature reserve which is overseen by the Ministry of the Environment. Captain Momadou Dia was identified as the manager of the Somone office for the ministry. Part of his role, and that of his staff, is to oversee activities at the Somone mangrove along the lagoon. Somone is a popular tourist destination and visitors have year-round access to the lagoon. Tourists were observed at the beach and participating in boat tours of the mangroves during the time of this study. Discussions with Captain Dia and his staff have noted that a volunteer group called the "Eco-guards" has been established by the Ministry to oversee the forests and charge admission to the beaches in Somone. According to Captain Dia and many Eco-guards interviewed for this study, the money collected for admission is shared with the community. Captain Dia and the Eco-guards also note that community engagement within the mangrove includes cleanup events in which community members remove litter and debris from the mangrove. It is unclear how community members are recruited for these activities (i.e. whether they are paid or volunteer) or if they address the cause of debris buildup within the mangrove.

In addition to active community engagement in preserving the mangroves, the women of the village have also established a means for income from the mangrove in Somone. The women collect oysters from the neighboring mangrove and cook and sell the oysters to tourists. Oysters are not extracted from the mangrove trees themselves, but oyster traps are placed in the water to catch the oysters. Captain Dia and many women and Eco-guards interviewed during this study noted that oyster extraction is prohibited for four months of the year to allow for the oysters to breed. Additionally, according to Captain Dia, various staff members, and Eco-guards, another rule-of-use established for the Somone mangrove prohibits cutting of the trees. The oyster extraction and tree cutting restrictions are enforced by the Eco-guards and by Captain Dia and the staff from the ministry during inspections of the mangrove. According to Captain Dia, one financial incentive established by the Ministry of Environment is a propane gas subsidy for community members to help deter wood extraction from the mangrove.

3.2 Survey Results

A summary of the survey sample demographics and ecosystem services responses are presented in the following sections.

3.2.1 Sample Demographics

A total of fifty-two people were surveyed in Bango (24), Dieul Mbam (15), and in Somone (13) during this study. Each questionnaire collected eight types of demographic information including gender, age, ethnicity, marital status, occupation, and education level (shown in Table 3-1.). The majority of individuals surveyed were female (65.4%) with most of the participants above 31 years of age (82.7%). An overwhelming majority of interviewees identified as married (82.4%) and included members of five ethnic groups: Wolof (55.6%), Lebou (23.1%), Peulh (13.5%), Serene (5.3%), and Mandinka (1.9%). The majority of survey participants listed their education level as either no early childhood education (48.1%) or having a primary education (30.8%). Further, the identified occupations amongst the participants were predominantly trader (44%), farmer (18%), and student (12%). The occupation "trader" used in this survey is a term for someone who bargains goods (i.e. fish and agricultural products) between community members in exchange for money or other services.

Table 3-1: Summary of Demographics

Gender		**Education**	
Female	65.40%	No Early Childhood Education	48.10%
Male	44.60%	Primary Education	30.80%
Age		Lower Secondary Education	11.50%
<20	7.69%	Upper Secondary Education	5.80%
20-29	9.62%	Post-secondary Education	3.80%
30-39	13.46%	**Occupation**	
40-49	26.92%	Trader	44%
≥50	42.31%	Farmer	18%
Ethnicity		Student	12%
Wolof	55.60%	Manager/Housewife	10%
Lebou	23.10%	Fisherman	10%
Peulh	13.50%	Retired	2%
Serene	5.30%	Driver	2%
Mandinka	1.90%	Teacher	2%

3.2.2 Ecosystem Services – Provisioning Services

Provisioning services listed in the questionnaire were those identified for both mangroves and forests to consider how people view the mangrove. Fish as a provisioning service

encompassed the extraction of seafood and clams and was a top provisioning service identified by survey participants in all three sites (Figure 3-1). In both Bango and Somone, fish was identified as a provisioning service by 100% of survey participants, and in Dieul Mbam, 92.8% of participants identified fish as a provisioning service. All survey participants in all three areas noted their household eats fish 7 days per week.

Despite the fact that mangrove trees are typically used for biomass, charcoal was the lowest perceived provisioning service in Somone (7.69%), with fiber (15.38%) and building material (15.38%) also selected at a low percentage. Similarly, in Dieul Mbam, building material (28.57%) and charcoal (35.71%) were the lowest selected provisioning services. These findings are consistent given mangrove managers in these two areas put tree cutting restrictions on their respective mangroves (see Section 3.1). Comparatively, Bango had higher percentages of respondents who perceived charcoal (72.27%), fiber (90.91%), and building material (77.27%) as previsioning services provided by the mangrove. Of the three villages surveyed in this study, Bango was the only village that does not have restrictions on cutting trees for extraction.

For medicine as a provisioning service, all participants in Somone identified this service as being provided by the mangrove, while only 72.73% in Bango and 42.86% in Dieul Mbam agreed. Upon further discussion with participants in Somone, it was acknowledged that mangrove leaves were used by their forefathers to brew a tea to treat stomach issues. When survey participants in Dieul Mbam were asked about this practice, it was noted that there is a different species of terrestrial tree that grows near their village that is used for the same ailment and is more accessible.

Water as a provisioning resource was included in the survey because freshwater is a typical provisioning service provided by forests (MEA, 2005). While 95.45% of participants in Bango and 92.86% in Dieul Mbam identified water as a provisioning services of the mangroves, only 38.46% of participants in Somone agreed. It is uncertain whether survey respondents use of water provided by the mangroves is for domestic or agricultural use (i.e. storing fish in the home until it can be dried and preserved) or if respondents selected the service because water is present in the mangroves.

Birds were identified as a provisioning services at a higher percentage in Bango (86.36%) compared to Dieul Mbam (35.71%) and Somone (30.77%). The low selection in Dieul Mbam is consistent with management practices in which prohibits catching of birds due to its proximity to

a marine protected area. In Bango, some survey participants noted that families will eat the birds if they can be caught. While in Somone, respondents noted that adults do not eat the birds, but the children will occasionally catch the birds for food, but not on a consistent basis.

A tall grass grows on the edges of the mangroves in Dieul Mbam and Bango and when dried, these grasses are used as hay for feeding livestock and constructing fences for property. Residents in Bango also noted that leaves are removed from mangrove trees to feed livestock. The presence of this hay and the use of the leaves resulted in 77.27% of participants in Bango and 92.86% of respondents in Dieul Mbam to select herbs as provisioning resource provided by the mangroves. No respondents in Somone identified herbs as a provisioning resource of the mangroves.

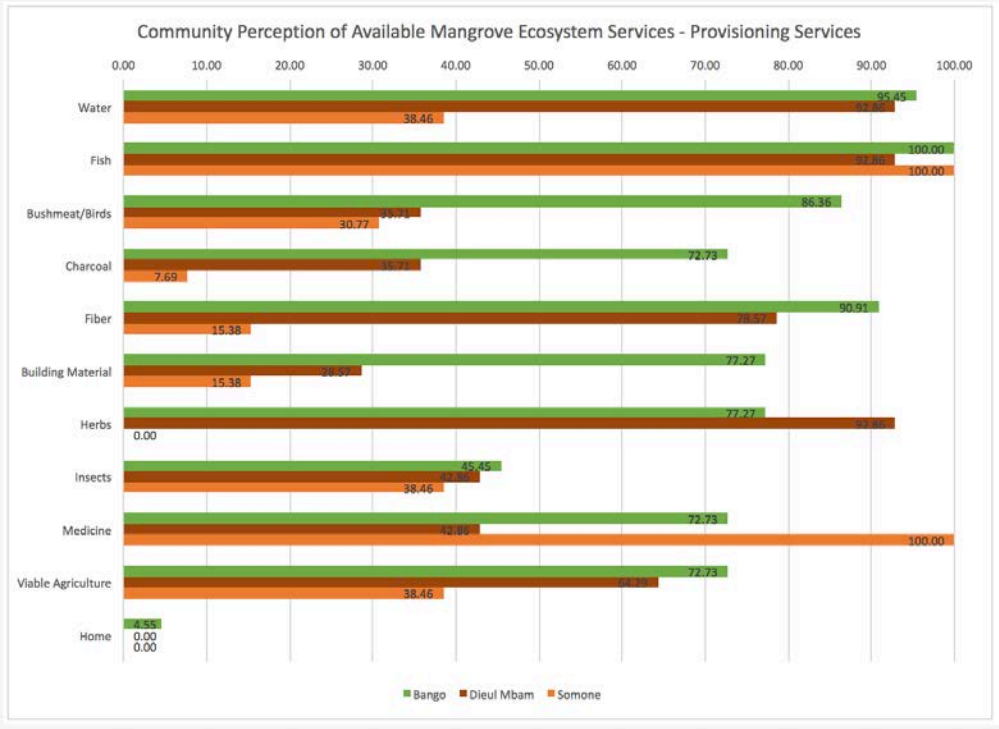


Figure 3-1: Community Perception of Available Mangrove Ecosystem Services - Provisioning Services

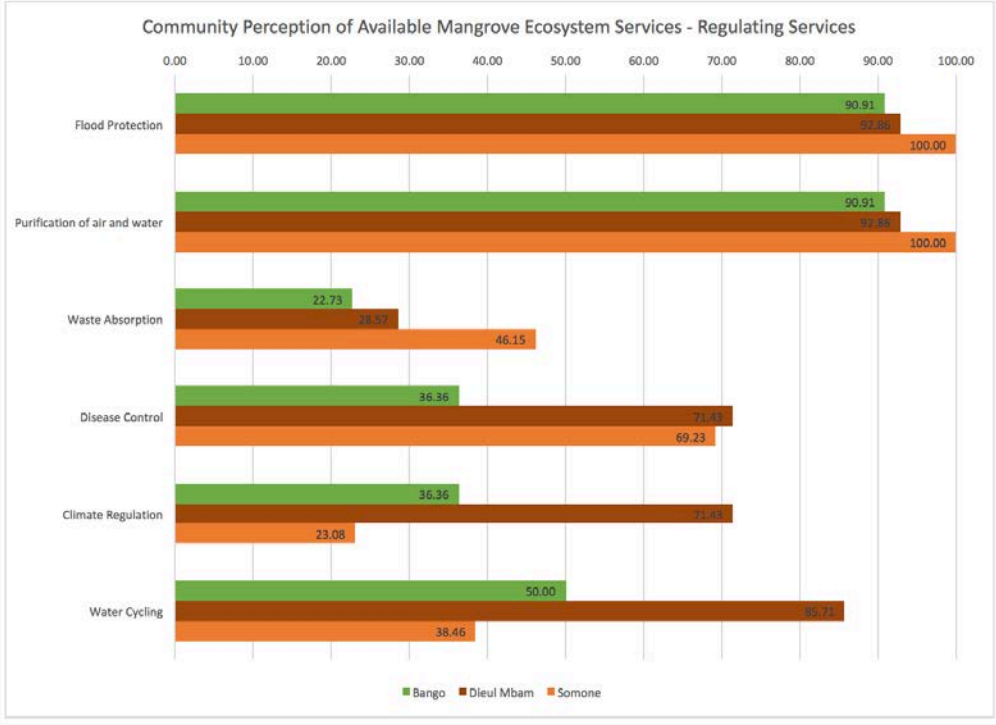
3.2.3 Ecosystem Services – Regulating Services

Flood protection and purification of air and water were the two most identified regulating services at all three sites (Figure 3-2). Both services were identified by 90.91% of participants in

Bango, 92.85% of participants in Dieul Mbam, and 100% of participants in Somone as being provided by their respective mangrove. The remaining four regulating services (waste absorption, disease control, climate regulation, and water cycling) were selected at varying percentages across each site.

In Bango and Dieul Mbam, waste absorption was the least selected regulating service among participants at 22.73% and 28.57%, respectively; while in Somone, 46.15% of participants selected waste absorption as a regulating service. Based on discussions with participants in Somone, it is perceived that respondents view trash and litter as a waste that is absorbed by the mangrove. This study could not discern whether survey participants in Bango and Dieul Mbam provided responses on waste absorption based on observed trash/litter in the mangrove or based on detoxification of waste that mangroves provide.

Dieul Mbam and Somone participants had a higher perception of disease control as a regulating service than Bango residents. Many of the 71.45% of residents in Dieul Mbam and 69.23% in Somone who selected disease control noted that they attribute this benefit to the wind coming from the mangroves that transports fresh air into the villages which, in turn, reduces the amount of disease within the community. Bango participants did not give any additional information on why they did or did not select disease control as a regulating service.



Services - Regulating Services

3.2.4 Ecosystem Services – Supporting Services

It should be noted that understanding and evaluating the supporting services associated with mangroves is highly technical and required detailed scientific explanation. The varying responses for these services could be a result of miscommunication between translators and survey participants. Fifty percent or more of Dieul Mbam participants viewed all supporting services as available from the mangrove, while the percentages in Bango and Somone varied between 13 and 85% (Figure 3-3). Survey participants did not offer any anecdotal follow-up explanations after selecting these supporting services like there were for other ecosystem services they seemed knowledgeable about. Therefore, this study could not discern whether the results were driven by participants in Dieul Mbam simply selecting all the choices that were available, and whether in other sites participants were accurately identifying these services as being available in their respective mangrove. That said, the result of more than 50% of participants in all sites acknowledging the more direct supporting services — photosynthesis, soil formation and nutrient cycling — as compared to lower and wider ranging percentages of participants acknowledging more indirect or complex services of carbon capture and crop pollination could be of interest to future research.

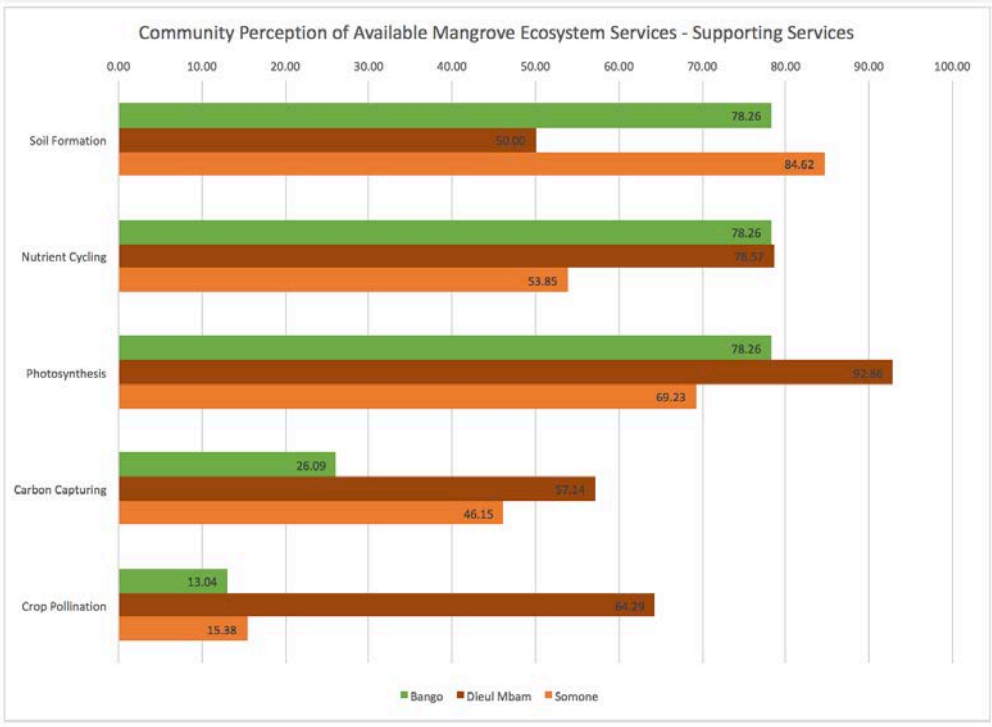


Figure 3-3: Community Perception of Available Mangrove Ecosystem Services – Supporting Services

3.2.5 Ecosystem Services – Sociocultural Services

Ecotourism was the most identified sociocultural service by all survey respondents in Somone while 81.82% of Bango participants and 78.57% of Dieul Mbam participants selected the service (Figure 3-4). All Somone survey participants in this study either work, or have worked in the area where community members sell oysters to tourists. This could explain the higher percentage of survey participants in Somone who identified ecotourism as a sociocultural service than in the other study areas.

Spiritual attachment was selected at a higher percentage in Dieul Mbam (35.71%) than in Bango (9.09%) and Somone (15.38%). As mentioned above, many residents of Dieul Mbam were displaced from a neighboring village which was historically located near a different mangrove but that mangrove is now dead and the village under water. A higher spiritual connection in Dieul Mbam could be the result of losing this former resource.

Indigenous/tribal knowledge was the second highest selected service at all sites with more than half of survey respondents selecting this service in all three study areas. Selection of this service was highest in Bango (77.27%) compared to Dieul Mbam (64.39%) and Somone (53.85%).

In Dieul Mbam (50%), recreation was selected at 5 and 7 times the percentages of Bango (9.09%) and Somone (7.69%), respectively. Recreation was the lowest selected sociocultural service in Somone at 7.69%. Many women of Dieul Mbam spend the day together in the mangrove while extracting clams from nearby waters and can be viewed as a social activity between the women.

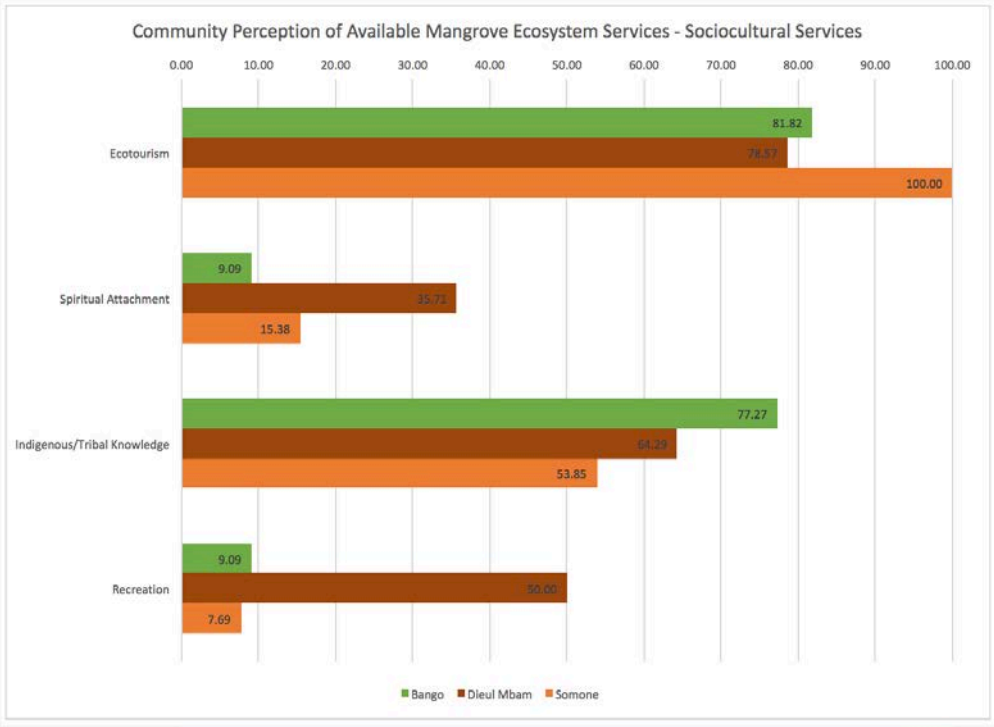


Figure 3-4: Community Perception of Available Mangrove Ecosystem Services - Sociocultural Services

3.3 Ecological Assessment Results

A summary of the tree health, biodiversity monitoring, and soil characteristic results are presented in the following sections.

3.3.1 Tree Health

Ten plots were assessed in the mangroves of Somone and Bango and twelve plots were assessed in Dieul Mbam. Using recent dieback as an indicator for plot area health, Somone overwhelmingly has the healthiest mangrove forest of all three areas and Bango, the least healthy. In Dieul Mbam, 58% of plots were designated as healthy, 17% as unhealthy, 8% as recent dieback, and 17% as old dieback (Figure 3-4a). In Bango, 60% of plots were designated as healthy, 10% as unhealthy, and 30% as recent dieback (Figure 3-4b). There were no plots designated as old dieback in Bango. In Somone, all plots were designated as healthy (Figure 3-4c).

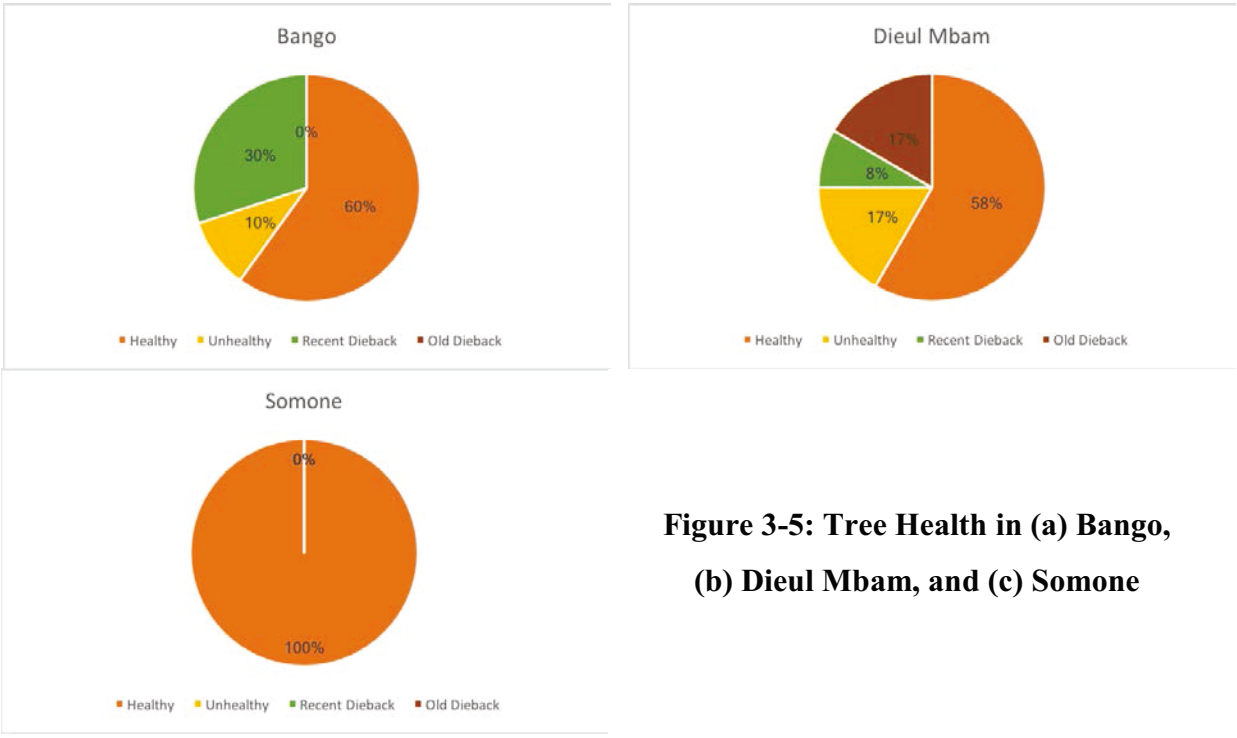


Figure 3-5: Tree Health in (a) Bango, (b) Dieul Mbam, and (c) Somone

The primary species of mangrove in Somone (100%) and Dieul Mbam (100%) was the *Rhizophora* species with one tree located within each plot area. In Bango, the primary species found in the plot areas was the *Avicennia* species. Many of the trees within the assessment plot areas at Bango contained multiple trunks, a consistent characteristic of the *Avicennia* species. Saplings present in the plots ranged from no saplings to as many as 6. In Dieul Mbam, saplings were present in three plots, while in Somone and Bango, a sapling were only present in one plot area at each location. The *Rhizophora* species had the most saplings growing within the plot area (4 plots) and also had the most number of sapling within the plot (6 saplings). Table 3-2 contains a list of the species and number of saplings found in each plot.

Table 3-2: Tree Species and Sapling Count by Site

Site	Plot	Tree Identification	Species	Number of Saplings in Plot Area
	SOMONE-P01	SOMONE-P01-01-AUGUST18	Rhizophora	0
	SOMONE-P02	SOMONE-P02-01-AUGUST18	Rhizophora	0
	SOMONE-P03	SOMONE-P03-01-AUGUST18	Rhizophora	0
	SOMONE-P04	SOMONE-P04-01-AUGUST18	Rhizophora	0
	SOMONE-P05	SOMONE-P05-01-AUGUST18	Rhizophora	0
	SOMONE-P06	SOMONE-P06-01-AUGUST18	Rhizophora	0
	SOMONE-P07	SOMONE-P07-01-AUGUST18	Rhizophora	0
	SOMONE-P08	SOMONE-P08-01-AUGUST18	Rhizophora	0
	SOMONE-P09	SOMONE-P09-01-AUGUST18	Rhizophora	3
	SOMONE-P10	SOMONE-P10-01-AUGUST18	Rhizophora	0
	DB-P01	DB-P01-01-JULY18	Rhizophora	0
	DB-P02	DB-P02-01-JULY18	Rhizophora	0
	DB-P03	DB-P03-01-JULY18	Rhizophora	0
	DB-P04	DB-P04-01-JULY18	Rhizophora	4
	DB-P05	DB-P05-01-JULY18	Rhizophora	6
	DB-P06	DB-P06-01-JULY18	Rhizophora	3

Site	Plot	Tree Identification	Species	Number of Saplings in Plot Area
	DB-P07	DB-P07-01-JULY18	Rhizophora	0
	DB-P08	DB-P08-01-JULY18	Rhizophora	0
	DB-P09	DB-P09-01-JULY18	Rhizophora	0
	DB-P10	DB-P10-01-JULY18	Rhizophora	0
	DB-P11	DB-P11-01-JULY18	Rhizophora	0
	DB-P12	DB-P12-01-JULY18	Rhizophora	0
		BANGO-P01-01-JULY18	Avicennia	
		BANGO-P01-02-JULY18	Avicennia	
	BANGO-P02	BANGO-P02-01-JULY18	Conocarpus erectus	0
		BANGO-P03-01-JULY18-TRUNK1	Avicennia	
		BANGO-P03-01-JULY18-TRUNK2	Avicennia	
		BANGO-P03-01-JULY18-TRUNK3	Avicennia	
		BANGO-P03-01-JULY18-TRUNK4	Avicennia	
		BANGO-P04-01-JULY18-TRUNK1	Avicennia	
		BANGO-P04-01-JULY18-TRUNK2	Avicennia	
		BANGO-P04-01-JULY18-TRUNK3	Avicennia	
		BANGO-P04-01-JULY18-TRUNK4	Avicennia	
		BANGO-P05-01-JULY18-TRUNK1	Avicennia	

Site	Plot	Tree Identification	Species	Number of Saplings in Plot Area
		BANGO-P05-01-JULY18-TRUNK2	Avicennia	
		BANGO-P05-01-JULY18-TRUNK3	Avicennia	
		BANGO-P06-01-JULY18-TRUNK1	Avicennia	
		BANGO-P06-01-JULY18-TRUNK2	Avicennia	
		BANGO-P06-01-JULY18-TRUNK3	Avicennia	
		BANGO-P07-01-JULY18-TRUNK1	Avicennia	
		BANGO-P07-01-JULY18-TRUNK2	Avicennia	
		BANGO-P07-01-JULY18-TRUNK3	Avicennia	
		BANGO-P07-01-JULY18-TRUNK4	Avicennia	
	BANGO-P08	BANGO-P08-01-JULY18	Rhizophora	0
		BANGO-P09-01-JULY18-TRUNK1	Avicennia	
		BANGO-P09-01-JULY18-TRUNK2	Avicennia	
		BANGO-P09-01-JULY18-TRUNK3	Avicennia	
		BANGO-P10-01-JULY18-TRUNK1	Avicennia	
		BANGO-P10-01-JULY18-TRUNK2	Avicennia	
		BANGO-P10-01-JULY18-TRUNK3	Avicennia	
		BANGO-P10-01-JULY18-TRUNK4	Avicennia	
		BANGO-P10-01-JULY18-TRUNK5	Avicennia	

3.3.2 Biodiversity Monitoring

Observers recorded an average of 330 birds at the Somone observation location, 22 birds in Dieul Mbam, and 8 birds in Bango. Individual bird species counts were not collected during this observation.

Table 3-3: Bird Observations by Site

Site	Observation 1	Observation 2	Average
Somone	305	355	330
Dieul Mbam	26	28	22
Bango	2	14	8

The investigation of crab boreholes in the mangroves resulted an average of 39 boreholes in Dieul Mbam and 6 in Bango. In Somone, two low-tide observation attempts, one in the evening and one in the early morning, were made to conduct borehole counts in the mangrove; however, a representative sample could not be established. Ripples were present in the sand during both observations which indicated a fast-moving tide. As such, some crab boreholes may have been covered by the moving sand during the tidal changes. Additionally, crabs were present and digging new boreholes during both observation times possibly because their holes had recently been covered by the moving sand. As such, the observer concluded the conditions at the time were not representative of actual borehole count due to the receding tide. Because of these inconsistences, crab borehole counts in Somone were disregarded from this analysis.

Table 3-4: Number Crab boreholes per Square Meter by Site

Site*	Plot C1	Plot C2	Plot C3	Plot C4	Plot C5	Plot C6	Plot C7	Plot C8	Plot C9	Plot C10	Average
Dieul Mbam	22	42	40	23	38	21	59	45	50	52	39.2
Bango	8	6	2	3	6	8	7	9	7	4	6

Note:

Crab borehole counts for Somone were not representative of actual conditions so they are not reported in this study.

3.3.3 Soil Characteristics

Overall, soil pH ranged from 5.4 in Bango to 7 in Dieul Mbam which is in the range of typical mangrove soil pH as noted by English et al. (1997). Somone had the narrowest range of pH ranging from 5.9 to 6.2. Bango had the widest range of pH ranging from 5.4 to 6.8. The soil pH in Dieul Mbam ranged from 5.8 to 7. At Bango and Somone all plot areas sampled had a soil moisture reading of 100%. In Dieul Mbam, the soil moisture ranged from 2% to 100%. In Somone and Dieul Mbam, all soil types were classified as sand. In Bango, five plot areas had soil types classified as sand and five plot areas classified as sandy clay.

Table 3-5: Soil Characteristics by Site

Site	Plot	Soil Type	Soil pH	Soil Moisture
	SOMONE-P01	Sand	6.2	100%
	SOMONE-P02	Sand	6.2	100%
	SOMONE-P03	Sand	6.1	100%
	SOMONE-P04	Sand	6.1	100%
	SOMONE-P05	Sand	6.2	100%
	SOMONE-P06	Sand	5.9	100%
	SOMONE-P07	Sand	6	100%
	SOMONE-P08	Sand	6.2	100%
	SOMONE-P09	Sand	6.1	100%
	SOMONE-P10	Sand	6.1	100%
	DB-P01	Sand	7	10%
	DB-P02	Sand	6.7	55%
	DB-P03	Sand	6.8	20%
	DB-P04	Sand	6.2	100%
	DB-P05	Sand	6.3	100%
	DB-P06	Sand	6.8	100%
	DB-P07	Sand	6.9	2%
	DB-P08	Sand	5.8	100%
	DB-P09	Sand	6	100%
	DB-P10	Sand	6.1	80%

Site	Plot	Soil Type	Soil pH	Soil Moisture
	DB-P11	Sand	6.9	80%
	DB-P12	Sand	6.5	100%
	BANGO-P01	Sand	6.2	100%
	BANGO-P02	Sand	5.4	100%
	BANGO-P03	Sand	NS	NS
	BANGO-P04	Sand	6.2	100%
	BANGO-P05	Sand	6.3	100%
	BANGO-P06	Sandy Clay	6.8	100%
	BANGO-P07	Sandy Clay	6.3	100%
	BANGO-P08	Sandy Clay	6.7	100%
	BANGO-P09	Sandy Clay	6.6	100%
	BANGO-P10	Sandy Clay	6.3	100%

NS – No Sample Collected

4.0 Discussion

The results of this study indicate is that mangrove management style and community knowledge have influences on mangrove forest health. Somone, the study area with management conducted by a national agency and coupled with actively facilitated community engagement, has the lowest percentage of recent dieback in trees and has the highest bird count among the three studied areas, both indicators of ecosystem health. Bango, the area with no management oversight, has the highest percentage of recent dieback in trees and the lowest bird count. Using recent dieback as an indicator of mangrove forest health, it appears that Somone had the healthiest mangrove system of all three study areas. The community of Dieul Mbam, which uses local community knowledge to establish rules-of-use for the mangrove, had a higher percentage of recent dieback than Somone, but less than that of Bango. To justify the connection between management, community engagement, and mangrove forest health, other potential explanations for the differences in mangrove forest health are ruled out in the following sections and further inquiry is placed into the influences of community knowledge and management styles.

4.1 Negating Rainfall and Soil Quality as Reasons for Mangrove Health Disparity

Although Somone is located further south than Dieul Mbam and Bango, rainfall amounts are ruled out as the cause of tree health disparity because the two areas receive roughly the same mean annual rainfall in an eight-year period (Bobée et al., 2012). In a rainfall analysis performed by Bobée et al. (2012), Saint-Louis (the city closest to Dieul Mbam and Bango) and Dakar (the nearest city in the study to Somone) received a mean annual rainfall of 282.5 ± 60.0 mm (mean ± standard deviation) and 296.2 ± 150.6 mm, respectively. These annual means are within a close enough range to negate rainfall amounts as the reason for the difference in tree recent dieback.

Soil pH is also ruled out as a cause for tree health disparity between our study areas. Mangrove soils typically have a pH within the range of 6 to 7 with some as low as 5 (English et al., 1997). The pH range between all three sites were relatively similar and within the typical range for mangrove soils. One plot within each study area (i.e. three plots total) had a pH below 6 but above 5; however, the majority of plots in each study area had a pH between 6 and 7. Also, pH was not indicative of individual tree health. Plots with trees categorized as healthy had pH as low as 5.4 and as high as 7. Comparatively, plots with trees categorized as recent dieback also had soil pH as ranging from 6.2 to 6.8.

4.2 Community Knowledge and Management Practice's Influence on Mangrove Health

Given the higher percentage of healthy trees in the Somone study area, without an exclusive environmental explanation (e.g. pH and rainfall), a closer look at management practices is warranted. Mangrove management authorities in Somone incorporate a combination of conventional resource management and Traditional Ecosystem Knowledge (Burkes et al. 2000) to manage the mangroves in the area. Restricting harvest times of some resources and banning harvesting of others are types of management system that incorporate social mechanisms and scientific ecology for conservation of the resource. This system is used in Somone by banning harvesting of oysters during four months of the year to allow for breeding. This system is also used to regulate biomass usage in both Somone and Dieul Mbam through bans on tree cutting and restrictions on the extraction of timber products. Somone has a complete ban on tree cutting and extraction while in Dieul Mbam, residents are banned from cutting trees but can extract branches that may have fallen to the ground. Bango does not have any established rules-of-use for the biomass in their mangroves which allows residents to extract wood at any

time. The survey results indicate community perception of biomass provisioning services in all three study areas is in line with these management practices. In the survey, building material and charcoal were two of the lowest ranked regulating resources in both Dieul Mbam and Somone while in Bango, these services were among the most selected provisioning services. Additionally, the ecological assessment also indicates the restrictive rules-of-use in Somone and Dieul Mbam result in less recent dieback of trees than the study area with no mangrove management. These results show that without restrictions posed by mangrove managers, people in the community view biomass resources as a benefit from the mangrove and will extract it for charcoal, fiber, and building material, thereby, having a negative impact on the health of the forest.

The responses for the indigenous/cultural knowledge service, a sociocultural ecosystem service, shows that Somone participants have the lowest perception of the service while Bango residents have the highest perception of the service. These responses are inverse to the health of the mangrove in that Somone has the healthiest mangrove (i.e. least recent dieback) and Bango the least healthy (i.e. the most recent dieback). Perhaps, it could benefit mangrove managers to get communities to internalize their generational knowledge of the mangrove and see this knowledge as a commodity. It seems that Bango is lacking what Burkes et al. (2000) considers a "cultural internalization" for mangrove management which would allow for local community knowledge of the mangrove to be embedded in its management and use the resource for extraction and improving the livelihood of the community.

Similarly, bushmeat/birds had a low selection percentage in the survey results in Dieul Mbam where the birds are under protection. This restriction accounts for the low number of participants identifying birds as a provisioning resource. Although the percentage of Bango residents selected bushmeat/birds at a higher percentage compared to the other two sites, the area had the lowest bird count. Somone has the highest bird count but the lowest percentage of survey participants who view bushmeat/birds as a provisioning service. Based on discussions during the survey, it seems that a higher number of Bango residents will catch the birds for food, while Somone residents note that only the children consume the birds. This study did not discern whether the low presence of birds is a result of harvesting rates/threats to the birds or a poor ecosystem, but the connection between the two is interesting and human consumption could potentially explain the low bird count in Bango.

Somone also had the highest percentage of participants who viewed waste absorption as a regulating service provided by the mangrove. Waste absorption is included as an ecosystem service due to biological mechanisms of the plant which facilitate oxidation, denitrification, and binding of organic wastes like carbon, nitrogen, and phosphorus (Tam and Wong, 1997). Of the survey participants in Somone who identified waste absorption as an ecosystem service, many noted trash/litter accumulation as their reason from selecting the service; therefore, it is assumed that participants in this study area view litter accumulation and as the "waste absorption" service provided by the mangrove. The participants also mentioned the trash cleanup events organized by the mangrove manager and Eco-guards as a way to help conserve the mangrove. There was no mention to trash cleanup activities in Bango and Dieul Mbam and it is unclear if participants in these study areas also perceive litter accumulation as waste absorption of the mangrove.

One unexpected result of the provisioning services was the selection of herbs by a large percentage of Dieul Mbam participants. Participants noted the historical use of mangrove leaves by previous generations as an upset stomach remedy. Again, many participants from Dieul Mbam came from a formerly adjacent village that had more accessibility to the mangrove and its resources. This type of Traditional Ecological Knowledge may play a larger part in the perception of herb availability as a regulating service.

5.0 Limitations and Future Research Considerations

While pH and rainfall are ruled out as reasons for mangrove health disparity between the three areas in this study, a closer look at nutrient availability differences between the three areas should be studied further because soil nutrient availability has been shown to influence the reproduction and growth rate of mangrove vegetation in West-Central Africa (Ukpong, 1997 and Feller et al., 2010). Rainfall and pH are two parameters that influence nutrient availability; however, given the similar mean annual rainfall amounts and similar pH ranges seen across all three sites, other parameters like soil salinity, nitrogen, and phosphorus concentrations could give a better explanation for the differences in recent dieback of the mangrove trees across these three sites. Additionally, *Avicennia* and *Rhizophora* mangrove tree species have been shown to need slightly different phosphorus and nitrogen requirements in order to photosynthesize (Robert et al., 2009). Given that the *Avicennia* species dominates the mangroves in Bango and

Rhizophora dominates in Somone and Dieul Mbam, a closer look at the nutrients found in the soils is warranted.

Tidal fluctuations also have an impact on nutrient availability and mangrove tree health (Feller et al., 2010); therefore, another consideration for future research would be a detailed look into the city of Saint-Louis's flood mitigation measures and the impact on Bango's mangrove. This study did not include a deep dive into Saint-Louis water management procedures and the adaptations implemented by the city; however, if flood protection measures do in fact limit or have changed historical tidal fluctuations of the mangroves in Bango, this could account for part or all of the recent dieback of the mangrove trees.

Time and budget constraints limited the scope of this study to three study areas and only two weeks per area. While these constraints do not impact the validity of this analysis, in the future it would be beneficial to have two or more study areas with the same management style (i.e. two or more areas with no mangrove management, two or more areas with local community management, etc.) to provide a comparison between styles. Additionally, larger survey and ecological assessment sampling sizes would be beneficial to allow for inference statistics to be completed on sampling results.

Language, translation, and ethnic group tensions should also be considered during future research in northern Senegal. During this study, two local languages namely Wolof and Pulaar were used as the primary mechanism for survey discussions and then translated into English. A local translator was present for each discussion to allow for real-time follow-up questions if necessary. Therefore, one limitation of this study is that it is possible that some information may have been lost or mistranslated during the course of the survey data collection. Additionally, the local translator that was used for all surveys conducted in June and July was of Peulh nationality while the translator for the August survey and discussions was of Wolof nationality. During an August discussion, a survey participant who self-identified as Wolof made a comment about traders of Peulh nationality which highlighted some biases towards the Peulh ethnic group. It is unclear whether June and July survey responses and translations were impacted by ethnicity differences and biases between survey participants and translators, but future research should consider these differences.

6.0 Conclusion

In conclusion, management policies like prohibitions and limitations on resource harvesting have influenced the health of the mangrove forests in study areas located in northern Senegal. Additionally, local community knowledge of mangrove function has also shown to influence mangrove forest health, specifically a reduction in damage to trees from cutting, through the implementation of rules-of-use based on Traditional Ecological Knowledge. Mangrove managers in other communities should find a way to internalize the cultural knowledge of local populations to establish rules-or-use that incorporate traditional practices and increase community engagement to help sustain their mangrove ecosystems. Additional research on the impact of nutrient availability of mangrove soils, soil and water quality differences study areas, and the impact of flood mitigation strategies in Saint-Louis are needed to paint a broader picture of how management style and community knowledge impact mangrove forest health.

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